AUTOBALANCE

Universal Bridge

B641

Operating Instructions

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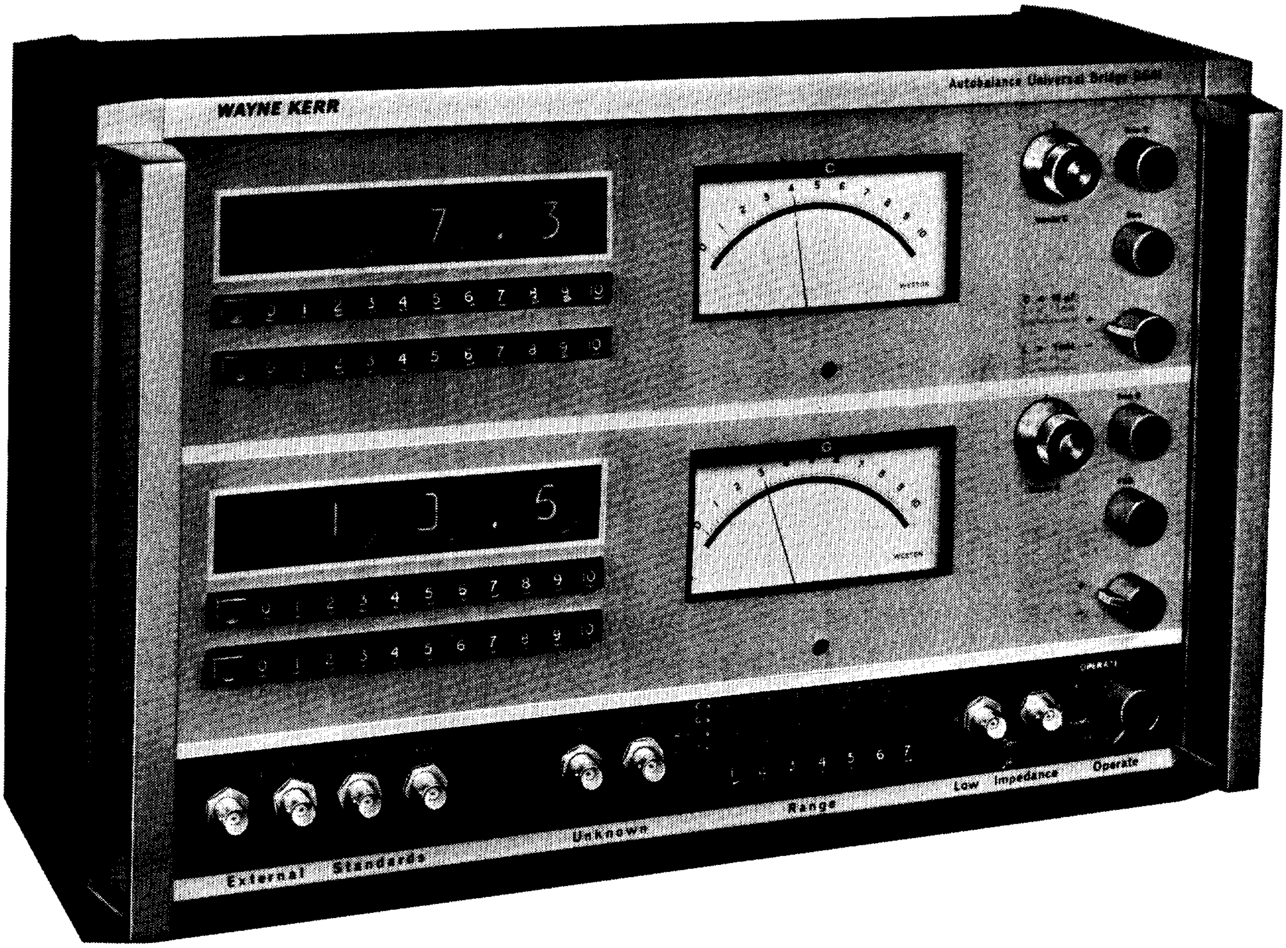
ILLUSTRATIONS AND TABLES



WAYNE KERR
Autobalance Universal Bridge B641
External Standards
Unknown
Range
Low Impedance
Operate

POWER SUPPLY

Note: Instruments are despatched with the internal transformer tappings set to suit the voltage of the local power supply. Regulation is adequate to compensate for all normal variations.

	A. C. Operation	Battery Operation
(a)	Open the right-hand panel door and set the switch to 'A. C. '.	Open the right-hand panel door and set the switch to 'Battery 9V'.
(b)	Push the supply connector through the aperture in the door and insert it in the 3-pin Supply socket. Close the door.	Wander plugs are provided in the 'Connect Battery' sockets. Leads from these can be taken through the door aperture to an external battery or d. c. supply (9V at 30mA). Connect the left-hand (black) plug to the negative terminal and the right-hand (red) plug to the positive terminal. Close the door.
(c)	Set the Operate switch to 'Supply' and check that the indication on the G meter is above the red mark on its scale. A 'Set Level D. C. Volts' control is provided but this should not normally require any adjustment. If the fuse has to be renewed, use only the same rating as fitted originally.	Set the Operate switch to 'Supply' and check that the indication on the G meter is above the red mark on its scale. If the indication on the G meter is below the red mark, renew the battery.

NORMAL MEASUREMENTS

This section describes two-terminal measurements using the Unknown sockets. At 1592c/s the coverage provided by these connections is capacitance up to 10µF, conductance up to 100mMho (resistance above 10Ω) and inductance above 1mH. For values outside these limits, refer to the section headed LOW IMPEDANCE MEASUREMENTS; for operation at other frequencies see 'External Source/Detector'.

Trimming/Calibration

1 Connect the crocodile-clip leads to the Unknown E and I sockets. Remove any connections from all other front-panel sockets.

2 Cross-connect the green leads from each cable to the metal sleeve and leave the red leads free (see illustration).

3 Press: Range button 1
All four 0 buttons (on the C and G decades)

4 Set: The Operate switch to 'Cal'
The Vernier C and Vernier G to '00' (fully counterclockwise)

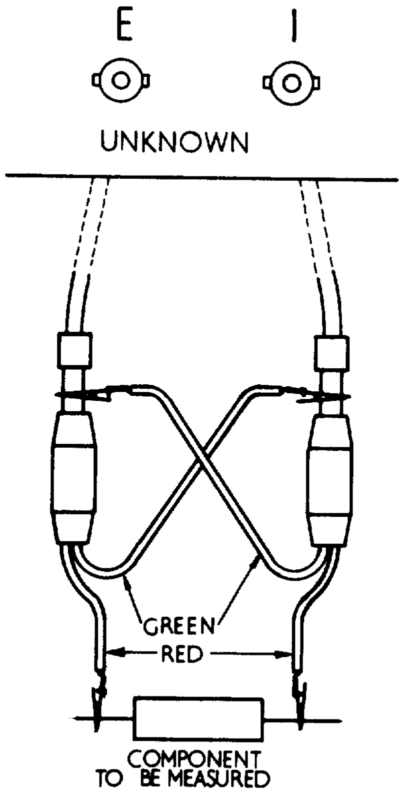
5 Adjust: Trim C for 0 reading on the C meter
Trim G for 0 reading on the G meter

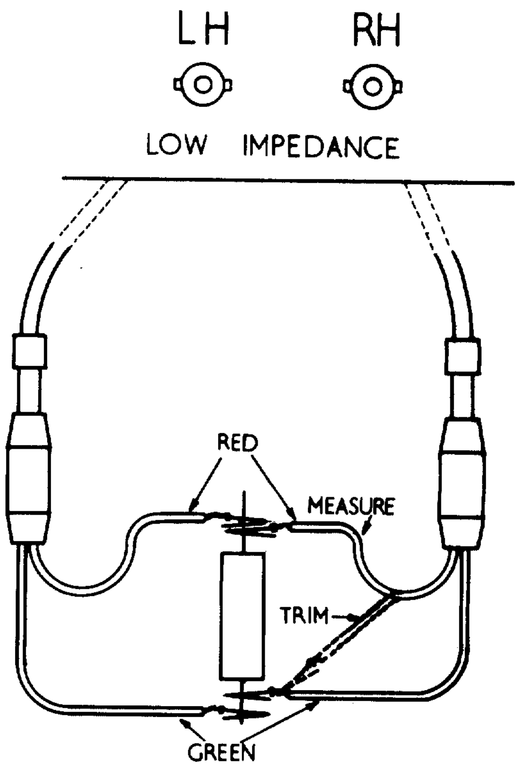
6 Press button 1 on the lower row of G decades.

7 Adjust the FSD control for full-scale deflection (10) on the G meter, and the Zero control for 0 reading on the C meter.

8 Press all four reset (red) buttons.

9 Set the Operate switch to 'OPERATE'. The Bridge is now ready for use and the Unknown can be connected between the two red leads. Although the trimming conditions established on Range 1 will be approximately correct onRanges 1-4, it is desirable always to check the trim on the range finally selected for measurement, with the settings of both +/- switches determined and any special jigs connected. This is particularly important when measuring small values of capacitance and when changing leads from the standard type to the Low Capacity Clip leads. The check can be made very quickly as described in step 10.





NORMAL MEASUREMENTS

(COMPONENT NOT CONNECTED DURING TRIMMING PROCEDURE)

LOW IMPEDANCE MEASUREMENTS

COMPONENT MUST BE CONNECTED FOR TRIMMING PROCEDURE, BUT WITH RED LEAD FROM THE RIGHT HAND CONNECTOR IN THE POSITION SHOWN IN BROKEN LINE

10 Disconnect either of the red leads (or either of the Low Capacity Clips) from one end of the Unknown. (If a jig is in use, leave the measurement leads connected to the jig but disconnect one lead of the component from the jig). Press all four 0 buttons, set both verniers to 00 and, with the bridge still in the OPERATE condition, adjust Trim C and Trim G for zero reading on the associated meters.

11 Re-connect the Unknown and re-press all four reset (red) buttons. The final measurement can now be made, in accordance with the appropriate instructions which follow. Note that the settings of the FSD and Zero controls, as made on Range 1, will hold good on all ranges and need not be re-checked.

<u>Capacitance Measurements</u>

1 When the Trimming/Calibration procedure has been completed, connect the 'unknown' capacitor between the two red leads. At this stage all four reset [red] buttons, and Range 1, should be depressed. If the correct Range setting and +/- settings are known, proceed to step 4.

2 Set the C and G polarity switches to '+'.

3 Observe the meter readings. If both lie between 0 and 1, change to Range 2 and if necessary (in sequence) to higher ranges until the larger meter reading is between 1 and 10. [If either meter reads above 10 on Range 1, the measurement lies in the Low Impedance range - see LOW IMPEDANCE MEASUREMENTS. If measurements are made on ranges 6 or 7, use the Low Capacity Clip leads (see next section)].

4 Note both meter readings.* If the capacitor has only a small loss term, the G reading will be near 0 and certainly less than 1. On the upper row of C decades, press the button corresponding to the first figure of the C meter reading, and 0 on the upper row of G decades.

5 The first figure of the capacitance now shows on the (upper) illuminated display with the second and third figures on the C meter. § Similarly, the (lower) G panel will show the loss term. By a similar process to step 4, set-in the first figure of each <u>new</u> meter reading on the lower rows of the C and G decades. ('0' if reading was below 1).

* and§ see footnote on page 6.

6 The C reading is now given to four figures - the first two and the decimal point on the (upper) illuminated display, the third and fourth figures on the C meter. Multiply the reading by the appropriate C factor (illuminated above the Range button in use).

7 Similarly, if the loss term (equivalent parallel conductance) is required, multiply the G reading by the appropriate Range factor. Alternatively, it can be read as equivalent parallel resistance from the expression R = 1/G, multiplied by the appropriate range factor for R.

8 If, on Range 7, the deflection of both meters lies below 1, press 0 on the upper C and G decades. Should both meters still read below 1, press 0 on the lower C and G decades to obtain maximum sensitivity.

9 If C is measured on Ranges 1 or 2, see 'Lead Corrections' (page 23).

Example (C)

(i) The Bridge has been trimmed and calibrated, and a capacitor connected between the red leads.

(ii) On Range 1, both meters show 0.

(iii) Press Range 2. Assume meters still read 0.

(iv) Continue increasing Range - 3, 4, etc. - until one meter reads over 1. Suppose on Range 5 the C meter reads 6·4 and the G meter about 0. [At this stage the trimming would be checked, as described in step 10 of the Trimming/Calibration procedure].

(v) Press 6 on the upper row of C decades and 0 on the upper row of G decades.

(vi) If C meter now reads the figures '38' and G meter about 0, press 3 on the lower row of C decades and 0 on the lower row of G decades.

(vii) The illuminated C display will now read 6·3 and the meter (say) '82'. The full reading is therefore 6·382.

(viii) The C multiplier illuminated for Range 5 will be x100pF.

(ix) The capacitance value is therefore 6·382 x 100pF = 638·2pF.

(x) Suppose the loss term produced a final G display (on the same Range, 5) of 0·0 (illuminated), and 3 minor divisions on the meter ('06'). This would represent a conductance in parallel with the capacitance of 0·006 x μ℧ = 0·006micromho (6nanoMho). Alternatively, it may be interpreted as an equivalent parallel resistance given by

$R = (^1/G) \times M\Omega = M\Omega/0{\cdot}006 \simeq 170M\Omega$.

The example serves to illustrate the point that the minor term cannot be expressed with any great accuracy when derived from a small meter deflection (whilst both decades are on zero). Meter accuracy is ±1% f. s. d. Thus a deflection of 3 minor divisions could represent a true reading of between 2½ and 3½ minor divisions. It should also be borne in mind that a small minor component has a negligible effect on the overall impedance (or admittance).

Low Capacity Clips

To obtain maximum accuracy when measuring small values of capacitance (Ranges 6 or 7), the plunger-operated low capacity clip leads should be substituted for the normal measurement leads. The green leads must be cross-connected to the metal sleeves in the same manner as with the normal leads, and re-trimming is essential.

Conductance and Resistance Measurements

Note: Because the Standards of the Bridge are effectively in parallel, basic calibration is in terms of conductance rather than resistance. However, the readout can be interpreted in either form by using the appropriate expression above the Range button in use.

1 When the Trimming/Calibration procedure has been completed, connect the 'unknown' resistor between the two red leads. At this stage all four reset (red) buttons, and Range button 1, should be depressed. If the correct Range setting and +/- settings are known, proceed to step 4.

2 Set the C and G polarity switches to '+'. Should the C meter show a reverse deflection, at any time, change the C polarity switch to '-'.

3 Observe the meter readings. If both lie between 0 and 1, change to Range 2 and if necessary (in sequence) to higher ranges until the larger meter reading is between 1 and 10. [Refer to LOW IMPEDANCE

MEASUREMENTS if either meter reads above 10 on Range 1].

4 Note both meter readings.* If the resistor has only a small phase angle (small reactance term), the C meter reading will be near 0 and certainly less than 1 (if the C meter reads below 0, reverse the setting of the C polarity switch). On the upper row of G decades, press the button corresponding to the first figure of the G meter reading, and 0 on the upper row of C decades.

5 The first figure of the conductance now shows on the (lower) illuminated display with the second and third figures on the G meter. § Similarly, the (upper) C panel will show the reactance term. By a similar process to step 4, set-in the first figure of each <u>new</u> meter reading on the lower rows of the G and C decades ('0' for C if reading was below 1).

6 The G reading is now given to four figures - the first two and the decimal point on the (lower) illuminated display, the third and fourth figures on the G meter. Conductance is given by multiplying the G reading by the appropriate factor illuminated above the Range button in use. Alternatively, resistance is derived from the G reading by use of the expression R = ($1/G$) multiplied by the appropriate Range factor for R.

7 Derivation of the reactance term is dependent on the setting of the C polarity switch.

On '+' : multiply the C reading by the appropriate factor for C, illuminated above the Range button in use.

On '-' : it may be more useful to interpret this as negative capacitance,

* If readings to only 2 significant figures are required, no further operations are necessary. Multiply the meter readings by the appropriate factor illuminated above the Range button in use.

§ If readings to only 3 significant figures are required, no further operations are necessary. Multiply the total reading (nixie - decimal - meter figures) by the appropriate factor illuminated above the Range button in use.

since this is a direct measure of the (positive) capacitance which, placed in parallel with the Unknown, would cancel out the inductive term. To obtain -ve C, use the factor and prefix the result with a minus sign.

To interpret the -C reading as inductance, use the expression*

L = ($^1/$-C) multiplied by the appropriate Range factor.

If G or R is measured on Ranges 1 or 2, see 'Lead Corrections' (Page 23).

Example (G/R)

(i) The Bridge has been trimmed and calibrated, and a resistor connected between the red leads.

(ii) On Range 1 the G meter reads 0·9 and the C meter 0.

(iii) Press Range 2. Assume G meter now reads the figures '86', C meter still 0.

(iv) Press 8 on the upper G buttons, 0 on the upper C buttons.

(v) Assume G meter now reads '63', C meter near 0.

(vi) Press 6 on the lower G buttons, 0 on the lower C buttons.

(vii) The illuminated G display will now read 8·6 and the meter (say) '27'. The full reading is therefore 8·627.

(viii) Multiplier for G on range 2 is x m℧.

(ix) The conductance value is therefore 8·627 x m℧ = 8·627millimhos.

(x) If the resistance value is required, instead of conductance, this is obtained from R = ($^1/$G) x kΩ = ($^1/$8·627) x kΩ = 116Ω.

(xi) If the final C reading (with the C polarity switch on '+') had been 0·0 (illuminated) and '01' (meter), the C value would be 0·001 multiplied by the C factor for Range 2 (x 100nF), giving a shunt capacitance of 0·001 x 100nF = 0·1nF (100pF).

* Valid at 1592c/s. At other frequencies use: L = $1/(\omega^2 C)$ where C is the value obtained using the reading multiplied by the C Range factor.

Inductance Measurements

The procedure is identical to that for capacitance measurements except that (step 2) the C polarity switch should be set to '-' instead of '+'. It should be borne in mind that the L value and any associated G (or R) represent the Unknown in terms of equivalent parallel components. Conversion formulae (parallel to series) are given on page 11. The expressions for L shown on the front panel are correct only for instruments operating at 1592c/s. At other frequencies, use the formula

$$L = 1/(\omega^2 C)$$ (see footnote on page 7)

Further information on operating procedures at frequencies other than 1592c/s is given in the section 'External Source/Detector'.

LOW IMPEDANCE MEASUREMENTS

This section describes two-terminal measurements using the Low Impedance sockets. At 1592c/s the coverage provided by these connections is capacitance exceeding 10μF, conductance exceeding 100mMho (resistance less than 10Ω) and inductance less than 1mH. For values outside these limits, refer to the section headed NORMAL MEASUREMENTS; for operation at other frequencies see 'External Source/Detector'.

Trimming/Calibration

1 Connect the crocodile-clip leads to the Low Impedance sockets. Remove any connections from all other front-panel sockets.

2 Clip the red and green leads from the left-hand cable (looking at the front-panel connectors) one to either side of the component to be measured, at least 1/4 inch from the body (see illustration facing page 2).

3 Clip the green lead from the right-hand cable to the component wire between the body and the 'left-hand green clip'.

4 Clip the red lead of the right-hand cable onto the 'green clip' of this same cable.

5 Press: Range button 1. All four 0 buttons (on the C and G decades).

6 Set: The Operate switch to 'Cal'
The Vernier C and Vernier G to '00' (fully counterclockwise).

7 Adjust: Trim C for 0 reading on the C meter.

Trim G for 0 reading on the G meter.

8 Press button 1 on the lower row of G decades.

9 Adjust the FSD control for full-scale deflection (10) on the G meter, and the Zero control for 0 reading on the C meter.

10 Set the Operate switch to OPERATE and, with all four 0's pressed, re-check the trim.

11 Press all four reset (red) buttons.

12 Transfer the red lead of the right-hand cable to the 'MEASURE' position (see illustration). The Bridge is now ready for use. The trimming/calibration will hold good when one Unknown is replaced by another.

Note: The impedance measured is ALWAYS that between the two clips from the RH cable (the other pair of clips being always outside these). Thus, for example, it is possible to measure the resistance per unit length of conductors.

Resistance Measurements

The procedure is basically the same as for NORMAL MEASUREMENTS (Resistance) except that

(a) no range-changing is made (Range 1 should be used).

(b) the final display is read directly in ohms.

(c) on LOW IMPEDANCE only, the C polarity switch should be set to '-' if any capacitance is present, and to '+' for any inductance (i. e. opposite settings to those for Normal Measurements).

(d) the bridge reads the equivalent SERIES impedance of the Unknown.

The sequence of operations, commencing with all four reset (red) buttons pressed, is:

1 Note both meter readings and set-in the first figure of each on the upper row of the associated decade buttons. (If the original reading exceeds 10, the measurement must be made using the Unknown sockets. For readings below 1, press the 0 of the associated upper decade buttons.

If the C meter reads below 0, reverse the setting of the C polarity switch).

2 Set-in the first figure of the new meter readings on the lower rows of decade buttons (again pressing 0 for readings below 1).

3 The G display can be read directly in ohms and the reactance term is given by the expressions above the Low Impedance sockets. The expression $\mu F = 100/(-C)$ applies only at 1592c/s. At other frequencies use $\mu F = 10^{10}/(\omega^2 C)$ where C is the numerical bridge reading. The minus sign on the panel, taken with the minus sign of the polarity switch, gives a positive capacitance value. On Low Impedance measurements the values derived from the bridge readings are the equivalent SERIES components of R and L, or R and C.

Inductance Measurements

The procedure is the same as given in preceding paragraphs for resistance measurements, bearing in mind that, on Low Impedance only, the C polarity switch is set to '+' for inductance measurements. The value is obtained from the C display by using the expression $mH = \frac{C\ reading}{10}$. Measurements of inductance, using the Low Impedance sockets, are NOT dependent on frequency.

Capacitance Measurements

The procedure is the same as given for Resistance Measurements, bearing in mind that, on Low Impedance only, the C polarity switch is set to '-' for capacitance measurements. The value is obtained from the C display by using the expression $\mu F = 100 \times \frac{1}{C\ reading}$. On Low Impedance, capacitance measurements are frequency-dependent and the expression above applies only at 1592c/s. At other frequencies, the full formula must be used:

$\mu F = 10^{10}/(\omega^2 C)$

where C is the numerical bridge reading.

PARALLEL/SERIES CONVERSIONS

Any impedance (or admittance) can be expressed in two ways:

(a) parallel components of the in-phase and quadrature terms

(b) series components of the in-phase and quadrature terms

Given values for the components in one form - (a) or (b) - values for the alternative form can be calculated to give an exact equivalent circuit at any one specified frequency of operation.

Because the Standards of the B641 Bridge are in parallel, the Unknown is measured in form (a). Expressions for obtaining the equivalent series components are given below. In the case of Low Impedance measurements, the bridge readings are in form (b).

$$R_s = 1/[G(1 + Q^2)]$$

$$C_s = C[1 + (1/Q^2)]$$

$$L_s = -1/[\omega^2 C(1 + 1/Q^2)] \qquad [Q = 2\pi fC/G]$$

$$X_s = X/[1 + (1/Q^2)]$$

where G and C are the values of the parallel components obtained from the bridge.

If $Q \gg 1$:

$R_s \simeq 1/Q^2G \qquad C_s \simeq C \qquad L_s \simeq 1/(\omega^2 C) \qquad X_s \simeq X$

If $Q \ll 1$:

$R_s \simeq 1/G \qquad C_s \simeq C/Q^2 \qquad L_s \simeq Q^2/(\omega^2 C) \qquad X_s \simeq Q^2 X$

PRINT-OUT FACILITY

Switch closures on the decade buttons are used to provide a Binary Coded Decimal output (1, 2, 4, 8; and 0) for printers. A further set of contact closures indicates the range in use. Additional contacts, normally closed, may be used to inhibit operation of the printer whilst any reset buttons are pressed, thus obviating spurious readings.

To simplify the BCD logic circuits, two diodes are incorporated. These are connected for positive Common rails and are rated at 160mA and 50 peak inverse volts. Connections for external diodes are provided to satisfy other requirements.

A zener diode circuit, incorporated for use with the U. S. C. Printer model 1600, produces a +12V line for the logic from the +33V auxiliary rail.

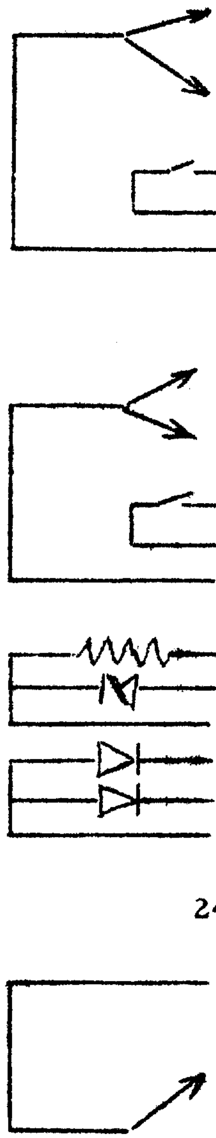
Coded outputs are in parallel form but the Common lines may be separated for certain types of serialiser.

The complete range of connections is shown on the accompanying diagram. This applies to C and to G.

DVM OUTPUTS

Voltage outputs proportional to the C and G meter readings are provided on the left-hand side panel. They provide 100mV at full-scale deflection, and the digital voltmeter connected to them should have an input impedance of not less than 100kΩ. Controls are provided for setting-up each output to the precise level required.

B C D PRINT-OUT CONNECTIONS



Pin No.	Function	
1	Carry 1	MAJOR (Upper) DECADE
2	1	
3	2	
4	4	
5	8	
6	0	
7	Reset	
8	Reset	
9	Common	
10	1	MINOR (Lower) DECADE
11	2	
12	4	
13	8	
14	0	
15	Reset	
16	Reset	
17	Common	
18	33V in	For use with USC Printer model 1600
19	Common -ve	
20	12V out	
21	*	DIODES
22	*	
23	*	
24-28	Spare	
29	Common	RANGE
30	1	
31	2	
32	3	
33	4	
34	5	
35	6	
36	7	

Note: Pins 7, 8, 15 and 16 of C are connected at the rear of the socket to the same number pins of G.

* To use internal diodes, link 21 to 3, and 22 to 4. This can be done externally (e. g. in the plug).

VERNIER CONTROLS

The C and G vernier controls have three functions:

1 They permit a meter deflection to be off-set
2 Used to 'back-off' a meter reading to zero, they provide enhanced discrimination
3 When the Bridge is operated with an external source/detector they are the fine balance controls.

Function 1 is particularly valuable for batch-testing of components and when a varying value is to be recorded. The vernier control is used to adjust the meter deflection to any desired position - for example to mid-scale. The Autobalance facility will then give continuous readings (and the monitoring outputs) for changes in either sense. Also, the meter scale could be marked for acceptable upper and lower limits to meet a required component tolerance.

Function 2 arises because the vernier controls can be read to three significant figures, compared with two figures on the meter. Also, the inherent linearity of the potentiometer associated with the vernier is better than that normally obtainable from a moving-coil meter. Allowing for backlash, the vernier reading taken when the meter deflection has been backed to zero, is about five times improved in resolution.

Function 3 arises because the Autobalance meter circuits are inoperative when an external source and detector are used. The operating procedure is given in the section 'External Source/Detector'.

The coverage provided by the Verniers is approximately equivalent to the full-scale range of a meter when both decades are in use. Because the meter sensitivity is reduced when only one decade, or no decades, are in use, the swing of the Verniers in these conditions is only about 10% and 1% f. s. d., respectively.

EXTERNAL STANDARDS

Four front-panel BNC connectors provide access to the -10 and -100 taps on the voltage transformer, and the +10 and +100 taps on the current transformer. By connecting external Standards to these points, a large part of any reading can be 'backed off', allowing the Bridge to be set to a more sensitive range to provide increased discrimination. Further uses include the accurate comparison of two components (for example, an external Standard in stabilised conditions could be compared with an 'Unknown' subjected to various environmental conditions), components can be measured against external preset Standards which could be switched in the form of a programme, also - over a wide range - two components can be compared, or matched, on a direct 1:1 basis.

The backing-off provides a discrimination of up to 100 times better than on a normal measurement. This is extremely valuable for the plotting or observation of small variations. It must be appreciated, however, that the same order of discrimination is applied to the External Standard component. For this reason it is usually necessary to use a component that is highly stable and whose value is known precisely or is adjustable. Also, the quality of the component must be sufficient to prevent its minor term - which may be magnified 10 or 100 times by the system - from causing errors. This is particularly important when an 'External Standard' is being used to balance out the major term of an 'Unknown' in order to allow closer examination of its minor term.

The operation of the Bridge with External Standards is described (a) as a Comparator (b) for increased discrimination. This is followed by (c) interpretation of results, and (d) extension of trim controls. The section ends with a table giving the values of the external standards required for backing-off. All information on this facility applies equally to capacitance and conductance measurements. In principle the use of the backwindings is equally applicable to Inductance, but in this case signs must be changed and ratios must be inverted. To avoid confusion, it is preferable to consider inductance as a negative capacitance component and convert to actual inductance units only for the final results.

(a) Comparator

The Bridge may be used for direct comparison of components, etc., with normal discrimination on Ranges 3, 4 and 5. For this purpose the Unknown should be connected in the normal way and the comparison component should be connected between the two inner connections of the appropriate 'External Standards' sockets to give the same turns ratio as for the Unknown (see table).

Before commencing the measurement, the bridge should be trimmed (with all the zeros pressed in the usual way) with all the leads connected to the appropriate sockets. The reset buttons should be engaged before both components are connected.

The full sensitivity of the bridge can then be achieved by engaging the decades (zero or digits as appropriate) and the resulting indication, in conjunction with the relevant Range multiplier, will be equal to the difference in value of the two components.

If it proves necessary to turn one of the Polarity switches to '-' to achieve a balance, this indicates that the 'unknown' component has a smaller capacitance or conductance than the 'External Standard' component. It is advisable to retrim the bridge after changing polarity.

To a limited extent, direct comparisons of components normally measured on Ranges 1 and 2 can be made on Range 3 with an incidental increase in discrimination. In both cases the E-10, I+10 External Standard windings are used and the bridge indicates difference directly (in conjunction with the Range 3 multiplier). If desired, the sensitivity can be reduced by pressing the reset button of either or both the decades, but the change in circuit conditions may give rise to an increase in effective meter sensitivity of up to 2% of f. s. d.

Components normally measured on ranges 6 and 7 may be compared directly using Range 5 for the Unknown and the E-100, I+100 External Standard windings, but in this case the discrimination is reduced accordingly. (At maximum sensitivity, with both decades in use, 10% f. s. d. on the meter is equivalent to 1pF on Range 5).

(b) Increased Discrimination

The discrimination of the bridge is improved by increasing the range position, but in so doing the balance of the Unknown goes outside the range of the internal standards. All or part of the Unknown Admittance may then be 'backed-off' by connecting to the External Standard windings a component that is selected as follows:

1 Select the Normal Range for the 'Unknown' component (i. e. one that gives an initial reading between 10% and 100% f. s. d. on the meter).

2 Refer to the Table to determine the discrimination available on this Normal Range and decide on the number of orders of increased discrimination required (a limit of two orders is recommended).

3 From the Table, select the appropriate column giving the required discrimination. This also specifies the increase in range setting required (the range position is shifted up once for each extra order of discrimination).

4 The three small columns give the values of 'External Standard' equivalent to Full Scale on the Normal Range of the Unknown component. Any one of the three values shown may be chosen provided that it is connected to the correct backwinding as indicated at the head of the column.

If the Unknown value is less than Full Scale the External Standard value must be reduced proportionally.

The above method holds in principle for any Range. In practice, however, a limit is reached on the high ranges when no further ranges are available to increase the discrimination, and on the low ranges, when the heavy loading that occurs will exaggerate the errors due to transformer and lead impedances.

Having determined the correct value and turns combination for the 'External Standard' and the required range, the measuring procedure is the same as before, i. e. the bridge is trimmed on the new range with the leads connected, the resets are engaged, both components connected and normal measurement carried out.

(c) Interpretation of results

Within the limits of accuracy obtainable, the bridge always indicates the difference between the admittance of the Unknown arm and the admittance of the External Standard arm transformed up or down to the level of the Unknown arm.

The External Standard is reflected into the Unknown arm as an admittance transformed by the ratio of the Unknown E and I turns product to the 'External Standard' E and I turns product.

Thus:

Effective Value of Ext. Standard reflected into Unknown arm

$$= \text{Value of Ext. Std.} \times \frac{\text{E turns} \times \text{I turns in Ext. Std. arm}}{\text{E turns} \times \text{I turns in Unknown arm.}}$$

The turns product of the unknown arm is, of course, dependent on the Range setting and can be found from the Table. The turns product of the External Standard arm is calculated from the turns shown above the socket in use.

For positive polarity:

$$\text{Bridge indication} = \text{Unknown value} - \left(\text{Ext. Std. value} \times \frac{\text{Ext. Std. turns product}}{\text{Unknown turns product}}\right)$$

The bridge indication is always taken in conjunction with the multiplier of the range actually in use.

When a polarity switch is turned to negative to balance the bridge, this implies that the Unknown Admittance is less than the reflected admittance of the External Standard. The above equation holds if the bridge indication is taken as a negative value.

(d) Extension of Trim

It is sometimes necessary to trim out the effects of special clips, jigs, etc., or even an unwanted shunt path that appears, effectively, across the Unknown. In cases where the coverage of the trim controls provided is inadequate or inconvenient, a suitably chosen component may be connected to the External

Standards windings. The required value is best obtained by measuring the shunt path on the bridge and referring to the 'Normal Discrimination' columns in the Table, exactly as if a comparator measurement was intended.

UNKNOWN		EXTERNAL STANDARD Value equivalent to full scale on Normal Range of 'Unknown'										
UNKNOWN VALUE	NORMAL RANGE (Turns in Unknown Arm)	NORMAL DISCRIMINATION (Select NORMAL Range)			10 x NORMAL DISCRIMINATION (Select ONE Range above NORMAL)				100 x NORMAL DISCRIMINATION (Select TWO ranges above NORMAL)			
		E-10, I+10	E-10, I+100	E-100, I+100	New Range	E-10, I+10	E-100, I+10	E-100, I+100	New Range	E-10, I+10	E-100, I+10	E-100, I+100
1μF - 10μF 10m℧ - 100m℧	Range 1 (E+1, I+1)	100nF 1m℧	10nF 100μ℧	1nF 10μ℧	Range 2	1μF 10m℧	100nF 1m℧	10nF 100μ℧	Range 3	10μF 100m℧ (Direct Comparison)	1μF 10m℧	100nF 1m℧
100nF - 1μF 1m℧ - 10m℧	Range 2 (E+1, I+10)	100nF 1m℧	10nF 100μ℧	1nF 10μ℧	Range 3	1μF 10m℧ (Direct Comparison)	100nF 1m℧	10nF 100μ℧	Range 4	10μF 100m℧	1μF 10m℧ (Direct Comparison)	100nF 1m℧
10nF - 100nF 100μ℧ - 1m℧	Range 3 (E+10, I+10)	100nF 1m℧ (Direct Comparison)	10nF 100μ℧	1nF 10μ℧	Range 4	1μF 10m℧	100nF 1m℧ (Direct Comparison)	10nF 100μ℧	Range 5	10μF 100m℧	1μF 10m℧	100nF 1m℧ (Direct Comparison)
1nF - 10nF 10μ℧ - 100μ℧	Range 4 (E+10, I+100)	100nF 1m℧	10nF 100μ℧ (Direct Comparison)	1nF 10μ℧	Range 5	1μF 10m℧	100nF 1m℧	10nF 100μ℧ (Direct Comparison)	Range 6	10μF 100m℧	1μF 10m℧	100nF 1m℧
100pF - 1nF 1μ℧ - 10μ℧	Range 5 (E+100, I+100)	100nF 1m℧	10nF 100μ℧	1nF 10μ℧ (Direct Comparison)	Range 6	1μF 10m℧	100nF 1m℧	10nF 100μ℧	Range 7	10μF 100m℧	1μF 10m℧	100nF 1m℧
10pF - 100pF 100n℧ - 1μ℧	Range 6 (E+100, I+1000)	100nF 1m℧	10nF 100μ℧	1nF 10μ℧	Range 7	1μF 10m℧	100nF 1m℧	10nF 100μ℧	NO RANGE AVAILABLE			
1pF - 10pF 10n℧ - 100n℧	Range 7 (E+1000, I+1000)	100nF 1m℧	10nF 100μ℧	1nF 10μ℧	NO RANGE AVAILABLE				NO RANGE AVAILABLE			

EXTERNAL SOURCE/DETECTOR

The B641 Autobalance circuits operate at a fixed frequency which is, normally, 1592c/s ($\omega = 10^4$). When operation is essential at other frequencies, an external source and detector can be employed. The illuminated numerals associated with the decades will still be operational but the two Vernier controls must be used for the fine balance in place of the meters. The BNC connectors for the external source/detector are fitted on the left-hand side panel. Beside these is a switch which must be set to EXT: this disconnects the internal source/detector circuits and brings the external connectors into circuit.

Source

The external source should be capable of providing up to 3V rms into an impedance of about 1kΩ (measured at 1592c/s). This level is recommended for all frequencies above 1592c/s: at lower frequencies the input level should be reduced in proportion (e. g. at half 1592c/s the maximum recommended is 1·5V rms). Higher levels can cause errors and possible damage to the Bridge: lower levels may be used, usually with a corresponding loss of discrimination. If any d. c. is present, this MUST be blocked off by means of a large series capacitor.

Detector

Ideally a current amplifier should be used, a sensitivity of about 700nA (0·7μA) into a short-circuit providing adequate discrimination. However, a high-gain voltage amplifier can be used, provided that it has an input impedance exceeding 100kΩ and a sensitivity of 5 - 10μV. It is usually necessary to ensure that the outer (screening) of the detector lead is grounded.

Operation

All the operations described elsewhere will apply, but the Bridge should be re-trimmed whenever the frequency of operation is changed. The disposition of the leads during trimming and measurement, the use of the Low Capacity Clips, and allowance for the series inductance of the leads and the bridge transformers all become increasingly important at the higher frequencies. When the source is first adjusted to the desired measurement frequency, and before the bridge is balanced, the detector should be tuned to the point of maximum response. As balance is approached the tuning of the source (not the detector) may need adjustment.

Readout

Normal measurements of Inductance made on the 'Unknown' sockets of the B641 are frequency-dependent. Also, measurements of capacitance (but not inductance) made on the Low Impedance connections, are frequency-dependent. For these two classes of measurement, the multiplying factors shown on the instrument panel will apply only at 1592c/s.

Inductance (Unknown sockets) is most easily derived by using the C multiplying factor for the range in use and then using the expression $L = 1/(\omega^2 C)$ where $\omega = 2\pi f$ and C is the value obtained after using the Range multiplying factor. The units are basic (L in Henrys, C in Farads). Thus 10^{-6} must be included if C is in μF, 10^{-9} for nF and 10^{-12} for pF. The expression can be written as

$$H = 1/(39{\cdot}48 f^2 C) \quad \text{(C in Farads)}$$

or $$\mu H = 1/(39{\cdot}48 f^2 C) \quad \text{(C in } \mu\text{F)}$$

or $$\mu H = 10^6/(39{\cdot}48 f^2 C) \quad \text{(C in pF)}$$

Capacitance (Low Impedance sockets) readings must take into account a multiplying factor which applies to all measurements made on these sockets (a factor which is incorporated in the panel expressions for 1592c/s readings). At other frequencies:

$$\mu F = 10^{10}/(\omega^2 C)$$

where $\omega = 2\pi f$ and C is the numerical reading on the bridge (decades plus vernier).

Accuracy

Bridge accuracy using the internal source/detector is 0·1% on C and G provided both decades are in use. Measurement of L is dependent on a precise knowledge of the bridge frequency, which is accurate to ±1%. The C and G accuracy obtainable at other frequencies is better than

±0·5%	200c/s - 10kc/s
±0·75%	100 - 200c/s and 10 - 15kc/s
±1%	50 - 100c/s and 15 - 20kc/s

These figures apply also to L measurement where frequency is known accurately: otherwise allowance must be made [L error will vary as $1/(\text{frequency error})^2$].

Low Impedance accuracy is given by adding '1' to the % figures quoted above. In this case the figures apply to L and R. For C, measure frequency or make due allowance [C error will vary as $1/(\text{frequency error})^2$].

BATTERY OPERATION

The procedure for connecting a battery is given on page 1. The measurement procedures are the same as for a. c. operation except that there are no illuminated displays. Thus the decades and range in use are shown only by observing which buttons are depressed. With both reset (red) buttons pressed, the decimal point lies between the two figures of all meter readings from 1 to 10. When the first (upper), or first and second, decades are in use (including 0's), the decimal point lies immediately after the first decade figure.

The switch should be returned to the 'A. C. ' position when batteries are disconnected, since subsequent connection to an a. c. supply would (with the switch still on 'Battery 9V') give an apparent fault condition with the illuminated displays lit but the source/detector circuits inoperative.

MEASUREMENT CONDITIONS

The voltage applied to the Unknown during measurement is approximately as follows:

Ranges 1 and 2	20mV rms (early instruments: 10mV)
Ranges 3 and 4	200mV rms(" " 100mV)
Ranges 5 and 6	2V rms (" " 1V)
Range 7	20V rms (" " 10V)

Low Impedance measurements are made using a constant current source (approx. 2mA rms, previously 1mA), and the small voltage developed across the component under test will depend on its impedance value.

Where measurements of polarised capacitors or energised inductors are required, suitable blocking capacitors must be incorporated to prevent d. c. reaching the bridge E and I sockets.

Also, some form of high impedance in series with the d. c. supply may be necessary to prevent the low impedance of the supply shunting the Unknown and so modifying its value. The effect of all decoupling arrangements can readily be checked by measuring the apparent value of a known component.

LEAD CORRECTIONS

To obtain maximum accuracy when making measurements on Ranges 1 or 2, a correction for the resistance and inductance of the leads and the Bridge transformers must be made.

<u>The resistance correction for Range 1</u> can be found by measuring a 10-ohm (20%) resistor, using both G decades, and noting the G meter reading (G1). Leaving the resistor connected, a second 10-ohm resistor (matched in value to within ±5% of the first resistor) is connected between the red and green leads of the E cable. The new G meter reading (G2) is noted and the difference between the two readings (G1 - G2) is recorded (value G3). With the first resistor remaining between the two rod leads, the second resistor is now transferred from the E cable to the red and green leads of the I cable, the G meter reading again noted (G4) and the difference from

the original reading (i.e. G1 - G4) is recorded (value G5). The differences that occur on loading are a measure of the series resistance which can then be read off the meter directly in <u>milliohms</u>. Thus f. s. d. on the meter (with both decades in use) represents 100mΩ.

The corrections obtained for the E and I leads should be added together. Alternatively the same values may be derived from the change in conductance values thus:

Series Resistance in milliohms = Total change in Reading (i.e. $G_3 + G_5$) in mMho x 100.

<u>NOTE:</u> Since only the <u>change</u> in reading is required, the appropriate Vernier control may be used to bring the meter reading to a convenient whole number before applying the loading.

In cases where the change in reading is greater than f. s. d., the next decade button should be selected to bring the reading back on scale and, of course, the total change in deflection must be noted.

To apply the correction the measured value should first be converted to a resistance, then the total series lead resistance may be subtracted to give the true value.

<u>The Inductance Correction for Range 1</u> is relevant to C and L measurements and can be obtained using the same method as for resistance (loading with 10Ω), except that the change in reading on the <u>C meter</u> should be noted. The series lead inductance for each half of the bridge can then be read directly, taking:

f. s. d. on C meter (with both decades in use) represents 10μH.

The total inductance is obtained by adding the two values. In the case of inductance measurements, the correction is applied by first calculating the equivalent Series Inductance of the Unknown:

$$L_s = \frac{-1}{\omega^2 Cp\left(1 + \frac{1}{Q^2}\right)}$$

then subtracting the total series lead inductance from this to give the true value.

Similarly, for capacitance measurements the parallel reading must first be converted to a series equivalent. This is best manipulated in the form of impedances, thus:

$$X_s = \frac{1}{\omega Cp(1 + \frac{1}{Q^2})}$$

The inductive impedance $-\omega L$ can then be added in series with this.

$$X_s \text{ (true)} = \frac{1}{\omega Cp (1 + \frac{1}{Q^2})} + (-\omega L)$$

This can then be converted back to a Capacitance

$$C_s \text{ (true)} = \frac{1}{\omega X_s \text{(true)}}$$

<u>Lead Corrections for Range 2</u> are determined exactly as for Range 1 except that a 100Ω Resistor is used for the 'Unknown' value with 10Ω as loading. As before, f. s. d. on the meter is equivalent to 100mΩ, but using the figures on this range:

> Series Resistance in milliohms = Total Change in reading (in millimhos) x 1000.

Lead Inductance is also given by the change in C meter reading, exactly as for Range 1 (f. s. d. ≡ 10μH). If the impedances have been determined on Range 1, the value found for the E side may be used for Range 2, since the transformer windings are common.

All the lead corrections are applied in exactly the same manner as with Range 1.

<u>Worked Example</u>

Measuring 10Ω on Range 1.

Unloaded reads 9.680 x 10mMho (G1)
-0.049μF

Loading E with 10Ω reads 9.572 (G2)
-0.061μF

Loading I with 10Ω reads 9.576 (G4)
0.061μF

E Lead Resistance (G1-G2) = 9.680 - 9.572 (G3)
= 0.108 x 100 <u>milliohms</u>

I Lead Resistance (G1-G4) = 9.680 - 9.576 (G5)
= 0.104 x 100 <u>milliohms</u>

Total lead resistance = (108 + 104) = 212 milliohms

These values confirmed by change in meter readings of

f. s. d. + 8% (G3) = 108 mΩ

and f. s. d. + 4% (G5) = 104 mΩ

Lead Inductance E = 0.061 - 0.049
= 12 ÷ 10μH = 1.2μH

I = 0.061 - 0.049
12 ÷ 10μH = 1.2μH

Total 1.2 + 1.2 = 2.4μH

<u>Measuring 1mH</u>

$$L_s = \frac{1}{\omega^2 Cp\,(1 + \frac{1}{Q^2})}$$

$$Q = \frac{9568}{1907} = 5.017$$

$$L_s = \frac{1}{10^8 \times 9.568 \times 10^{-6}\,(1 + 0.0397)}$$

$$= 1.005(23)\ \text{mH}$$

Subtract Lead
Inductance (2 x 1.2μH) = 1.0028(3) mH.

<u>Measuring 3mH</u>

$$L_s = \frac{1}{\omega^2 Cp\,(1 + \frac{1}{Q^2})}$$

$$Q = \frac{329}{035} = 9.4$$

$$\frac{1}{Q^2} = 0.0113(172)$$

$$L_s = \frac{1}{10^8 \times 3.29 \times (1 + 0.0113)}$$

$$= \frac{10^{-2}}{3.32724}$$

$$= 3.0058\ \text{mH}$$

Subtract Lead
Inductance = 3.003(4) mH.

[End of amended text]

3- AND 4-TERMINAL OPERATION

When a component, such as a small-value capacitor, is mounted in a screening box, the Neutral connection from the Bridge should be connected to the box. One green lead should remain cross-connected (from E to I or vice versa) and the second green lead provides the desired Neutral connection.

When four-terminal networks such as filters or attenuators are to be measured, the two leads from the E cable provide the input connections and the two I leads connect to the output terminals. In each case the green leads must be to the 'return' side of the network (a red-to-green 'crossover' must be avoided).

The neutral (green lead) of the E cable is connected, in the Bridge, to ground. The I neutral is floating.

MULTIPLES

10^{12}	Tor	T
10^{9}	Giga	G
10^{6}	Mega	M
10^{3}	Kilo	k
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

SPECIFICATION

Overall Ranges	C	0·002pF - 50000μF
	G	20p ℧ - 500℧
	L	200nH - 5MH
	R	2mΩ - 50000MΩ

Accuracy	0·1% from 1pF to 10μF 10n℧ " 100m℧ 1mH " 10kH 10Ω " 100MΩ
Discrimination	0·01% of max. on all ranges
Frequency	Internal source/detector: 1592c/s ($\omega = 10^4$) ±1% External " " 50c/s - 20kc/s
Comparator	(see page 16)
Outputs	From C and G Autobalance circuits: 0 - 100mV into ≮ 100kΩ. BCD (1248) outputs for Printers from each decade on both C and G. Outputs also provided from Range switch.
Ambient	Operates over temperature range 0 - 40°C.
Power Supply	115 or 230V, 40 - 60c/s, or external 9V battery.
Dimensions	Width: 19 in. (48 cm.) Height: 12¼ in. (31 cm.) Depth: 6 in. (15 cm.)
Weight	28 lb. (12·7 kg.)